simultaneous achievement of three conditions: homogeneity of pressures (mechanical equilibrium), homogeneity of temperature (thermal equilibrium), and homogeneity in chemical potential (diffusive equilibrium); i.e., *only* if all three conditions ($P^A = P^B$, $T^A = T^B$, and $\mu^A = \mu^B$) are simultaneously met can we affirm that the system will not change in time if left alone.

Solution #1, as Missen and Smith note, pertains to the achievement of mechanical equilibria, but as is also noted in the original article, leaves a temperature gradient among tanks A and B. Given enough time, mass diffusion must take place, transferring *energy* from tank B to tank A. So, even though tank B has adiabatic walls and thus no heat transfer to the surroundings, it does transfer energy due to a temperature difference.

In hindsight, the phrase "Given enough time, this temperature gradient will produce a transfer between the tanks" should read, "Given enough time, this temperature gradient will produce a mass transfer and consequent energy transfer between the tanks" in order to be unambiguous.

It is clear, however, that there are not two solutions to the problem, even if the catchy title implies so. Only one solution is possible. Any argument attempting to set solution #1 as the correct one must first disprove solution #2—an impossible task.

Many students and teachers (and Spicer's note is a clear example) apply the textbook equations directly to a problem without further thought on the problem. It is in this sense that I totally agree with the second point noted by Missen and Smith. I believe that one should teach the general energy balance, and for each particular case simplify it accordingly.

The point of the original class problem is that if one starts directly with Eq. (2), one may elude some of the assumptions behind its derivation. One should always start with a generalized equation such as Eq. (7)* and integrate it according to the given problem. Categorizing systems as steady state, uniform flow, etc., and stating formal equations in each case only entices the student to learn a myriad of equations, making things more difficult and prone to errors.

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* Equation (7) is identical (with the exception of the arbitrary sign given to the work) to Eq. (A) of Missen and Smith, not to Eq. (E) as stated in their comment.

ChE book review

Advanced Transport Phenomena

by John C. Slattery
Published by Cambridge University Press, The Edinburgh Building, Cambridge, UK; 734 pages; available in paperback and hardcover

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Advanced Transport Phenomena is a new textbook written by Professor J.C. Slattery that represents a revision of an earlier text by the same author: *Momentum, Energy and Mass Transfer in Continua* (1981). Transport phenomena is a fascinating and interdisciplinary subject that is covered by at least one required course in all graduate chemical engineering programs and remains an active area of research. Like its predecessor, the new book is intended for graduate students in engineering.

The text is organized into three topics according to the main subjects of transport phenomena: momentum, energy, and mass transfer. In addition, there are two shorter topics that are covered; kinematics (coming before the three main topics) and tensor analysis (an appendix). Each of the three main topics is divided into three sub-topics that can roughly be described as the formulation, application, and reduction of transport balance equations. This matrix style of organization, where the columns are the main topics (momentum, heat, and mass) of transport phenomena and the rows provide the components and applications for each topic, is similar to that used in the classic text *Transport Phenomena* by Bird, Stewart, and Lightfoot (BSL), and allows the instructor/reader the flexibility to cover the topics by column or by row.

The style and teaching philosophy of the author are revealed in Chapter 1 (kinematics) where concepts such as motion, velocity, and phase interfaces are introduced. Various transport theorems are developed and used to derive the differential mass balance, or continuity equation, and the jump mass balance from the mass conservation postulate. Hence, the approach taken here and throughout the book is to start from general postulates about the physical world and to convert these postulates into useful conservation equations using formal mathematical tools.

The sub-topic structure is itself instructional in that the reader is forced to recognize the similarities (and differences) between momentum, heat, and mass transfer. In Chapters 2, 5, and 8 (Foundations for...), differential forms of the conservation equations and their corresponding two-dimensional forms (jump balances) are derived simultaneously.

This is followed by rather lengthy developments on the behavior of materials where the most widely used (classical) constitutive equations are eventually presented. In Chapters 3, 6, and 9 (Differential Balances in...), various transport problems are formulated using the conservation and constitutive equations derived in preceding chapters. These problems, which range in complexity from one-dimensional, steady-state problems to two-dimensional problems that include boundary-layer theory, are solved using both analytical and numerical techniques. Chapters 4, 7, and 10 (Integral Averaging in...) are devoted to deriving reduced forms of the differential balance equations: time-averaged (turbulent flows), area-averaged, local volume-averaged (pseudo continuous media), and global volume-averaged (macroscopic balances).

Appendix A provides a comprehensive review of tensor analysis and includes operations in both rectangular Cartesian and curvilinear coordinate systems.

Scattered throughout each chapter are several worked examples, and each chapter ends with a series of exercises (for which a solution manual is available). At the end of each "Foundations of..." chapter, there is a summary subsection where the reader will find tables with the conservation equations expressed in rectangular Cartesian, cylindrical, and spherical coordinate systems.

There is no question that *Advanced Transport Phenomena* is a comprehensive and carefully prepared textbook. The use of material volumes and transport theorems (rather than stationary differential volumes, as is BSL) to derive differential conservation equations is appropriate for graduate-level courses. Significant attention is given to the behavior of materials and to the entropy inequality and its use in the formulation of constitutive equations.

Another positive aspect of this book is the utilization of jump balances to derive boundary conditions. Jump balances are rarely covered in modern texts on transport phenomena, but are invaluable in situations involving free and/or moving boundary problems. I particularly like the tables in Chapter 2 where the jump mass and jump linear momentum balances are given for several special surfaces in the three main coordinate systems.

Where the optimal balance is between being mathematically rigorous and comprehensive while also developing physical insight on transport problems is, of course, a matter of preference. Many readers of this book might find that there is too much emphasis on the first two at the expense of the third. As I read through certain portions of the book, I sometimes found myself leafing through page after page of derivation to find the punch line. (From my own rough estimate, there are on average a little more than seven equations per page, or, in the 700-page book, a total of about 5000 equations!) For example, in section 5.3, roughly ten pages are used to transform some general postulates about the thermal behavior of materials into useful results (*i.e.,* viscosity and thermal conductivity are positive, Fourier's law, internal energy can be expressed in terms of density, pressure, temperature, and a heat capacity). Unfortunately, discussion about the physical implications for the different constitutive assumptions used in the development is scant.

Another comment is that the book is almost comprehensive to a fault. For example, readers may find the results from the integral averaging chapters of marginal value, either because the subject is too complex to be developed at an advanced level (*e.g.,* turbulence and pseudo continuous media), or because it was too simple and therefore inappropriate for a graduate-level text (*e.g.,* macroscopic balances). Also, it is unlikely that one will find a situation that calls for the macroscopic moment-of-momentum balance or the jump entropy inequality. These portions of the book could have been better used to provide more physical insight or to analyze moving boundary problems, which are so prevalent in materials science and engineering. Having said that, educators and researchers in this field will be glad to have a single book where the equations needed to handle such a wide variety of transport problems can be found.

Advanced Transport Phenomena is a comprehensive textbook that provides systematic coverage of a challenging subject. It can be used as a primary text for a first-year graduate course on transport phenomena; students with prior exposure to the subject at the level provided by BSL will have a sufficient background. It could also serve as a solid reference book for more advanced graduate courses on fluid mechanics or on heat and mass transfer. My overall impression of the book is positive; I recommend it to those with an interest in teaching graduate-level transport phenomena or to those interested in learning advanced topics in this important and fascinating field. ❐